The Virtual Workshop OpenWinD : a Python Toolbox Assisting Wind Instrument Makers

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THE VIRTUAL WORKSHOP OPENWIND : A PYTHON TOOLBOX ASSISTING WIND INSTRUMENT MAKERS

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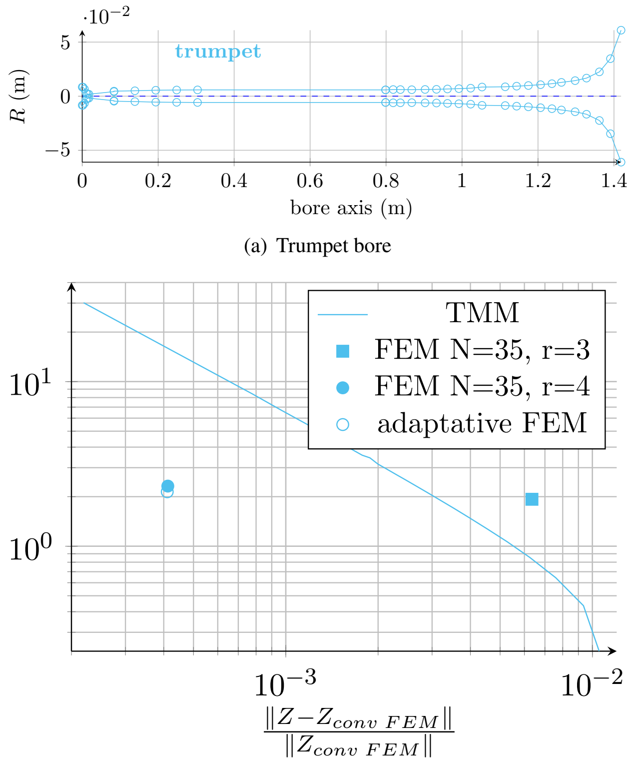
ABSTRACT

Our project develops the software OpenWInD for wind instrument making. A first feature is the prediction of the acoustical response of the instrument from the knowledge of its shape (bore and holes). This can be done in the harmonic (impedance computation) and temporal (sound computation) domains. It can account for various physical situations (non constant temperature, coupling with an embouchure, ...). Discretization is done in space with 1D spectral finite elements and in time with energy consistent finite differences. The second feature is the reconstruction of the shape of an instrument that fulfils a certain objective. This can be used for bore reconstruction, and instrument design. The latter is based on a strong interaction with makers and musicians, aiming at defining interesting design parameters and objective criteria, from their point of view. After a quantitative transcription of these criteria, under the form of a cost function and a design parameter space, we implement various gradient-based optimization techniques. More precisely, we exploit the fact that the sound waves inside the instruments are solution to acoustic equations in pipes, which gives us access to the Full Waveform Inversion technique (FWI) where the gradient is characterized as the solution to another wave equation. The computational framework is flexible (in terms of models, formulations, coupling terms, objective functions...) and offers the possibility to modify the criterion by the user. The goal is to proceed iteratively between the instrument makers and the numerical optimisation tool (OpenWInD) in order to achieve, finally, criteria that are representative for the makers. In the presentation, we will demonstrate and discuss some comparisons between measurements and simulation on real instruments.

1. INTRODUCTION

OpenWInD software aims at solving state-of-the-art models in musical acoustics for wind instruments with accurate, robust and efficient techniques from scientific computing science and numerical analysis. It allows the direct computation of the acoustical frequential response (input impedance) of a given instrument (knowing its bore and side holes geometrical parameters), or of the sound of this instrument when coupled to different types of excitators (reed, lips). It also relies on inversion techniques used in the field of geophysics (Full Waveform Inversion, [1]) to perform reconstructions from measurements and investigate some sensitivity characteristics of the instruments.



(a) Trumpet bore

(b) CPU time w.r.t. impedance relative ℓ^2 error.

Figure 1. Comparison between TMM and FEM method for the computation of a trumpet input impedance with viscothermal effects. Number of elements N, order of elements r.

2. DESCRIPTION

Finite Elements Method (FEM) is used in OpenWInD to perform the spatial discretisation of the 1D pipe equations (Telegraphist' equations with viscothermal effects, also called Zwikker-Kosten equations, or their approximations [2–4]). A quantitative comparison between Transfer

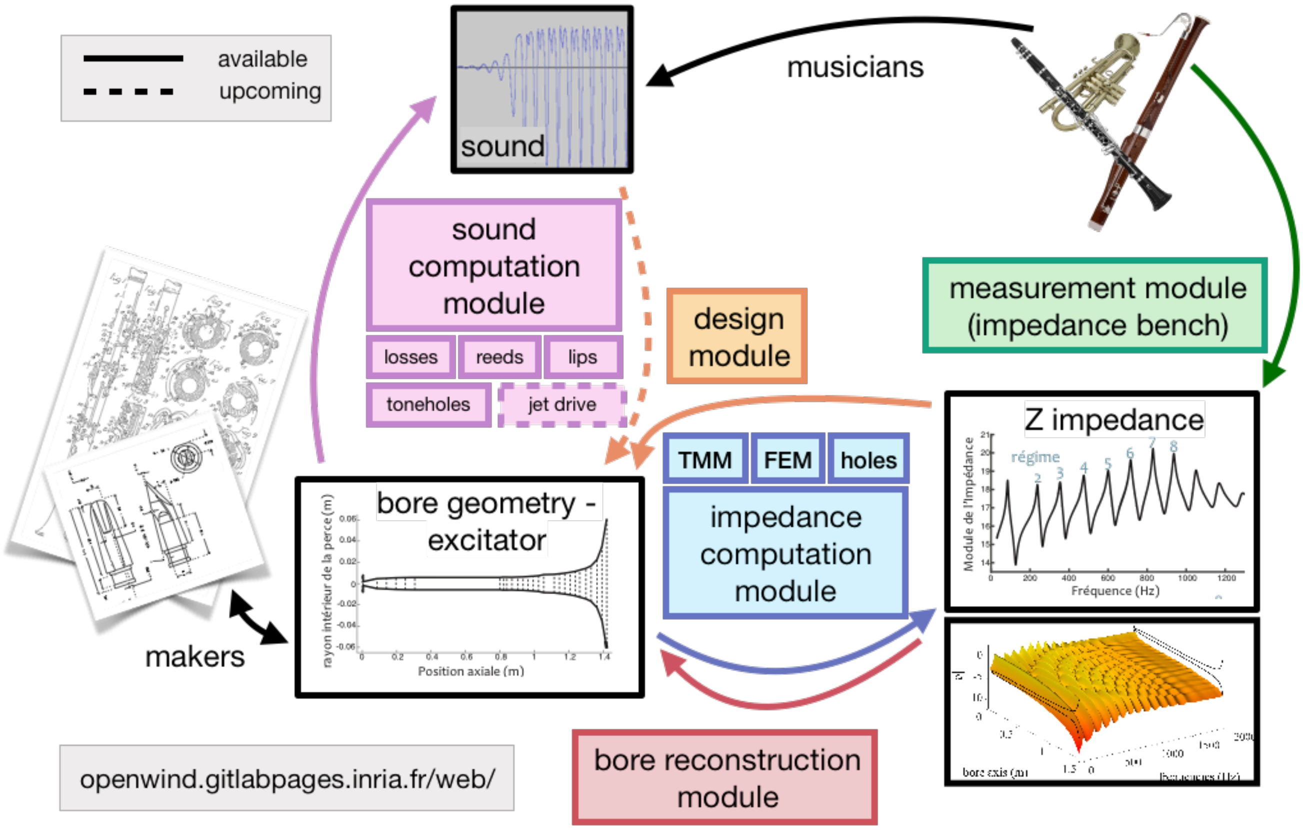


Figure 2. Schematic view of the different features of OpenWInD

Matrices (TMM) and 1D FEM methods for the computation of a trumpet input impedance [5] yields the result displayed in Fig. 1 : for arbitrary bores and in the presence of viscothermal effects, the FEM provides more accurate results (relative ℓ^2 error smaller than 1 %) for a lower computational cost, which makes it a good candidate for musical acoustics purposes. It constitutes a variational approximation of the pipe equations, suitable for energy consistent time-stepping strategies allowing the coupling with various elements such as nonlinear excitators, pipe junctions or radiation conditions (see [6]). The FEM generalizes the method used in [7] where a low order approximation is performed. Moreover, it provides an efficient framework for the computation of the gradient of the acoustic field with respect to design parameters, as the bore radius or the side holes parameters (see [8]).

Fig. 2 shows the modular organisation of OpenWInD. Several features are available in the public version of OpenWInD [9], released under GPLv3 licence, as input impedance computation of arbitrary shaped instruments with side holes (see [5]), sound computation with reeds and lips, sensitivity maps (see Fig. 4) and bore reconstruction from measurements.

3. ASSISTING INSTRUMENT MAKING

In the context of our collaboration with Humeau Factory, a measurement impedance sensor has been built following the principles described in Gibiat [10] with five microphones. It can be observed in Fig. 3 during a measurement campaign of a Humeau baroque bassoon.

Figure 3. Measurement of a Humeau baroque bassoon with our impedance sensor.

Humeau baroque oboes have been measured with a staple, and compared with simulation. Fig. 5 displays the input impedance of simulated (blue) and measured (orange) input impedance for the B1 note (only the first hole is closed). The inner bore as well as holes positions and geometries are known by the maker, but the staple was acquired elsewhere, so its geometry is poorly known. The length of staple / oboe interlocking is adjusted manually by the player and difficult to assess experimentally. Moreover, baroque oboes have three double holes that the current model in OpenWInD does not yet model correctly

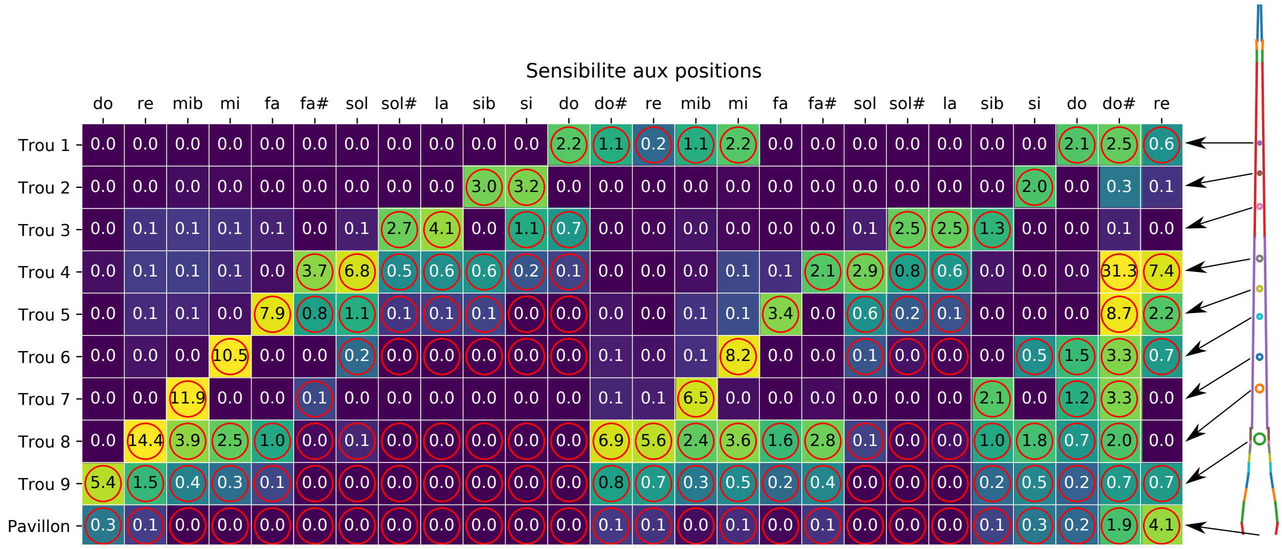


Figure 4. Sensitivity map of a Humeau baroque oboe, sensitivity of the input impedance w.r.t. the holes position. Open holes of each fingering are circled in red.

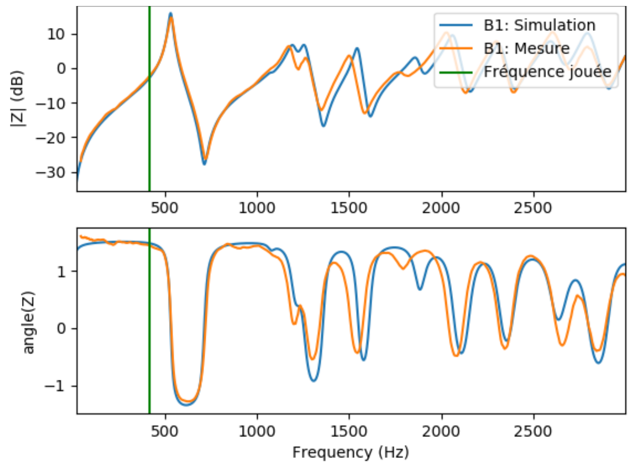


Figure 5. Impedance modulus (top) and phase (bottom) of a Humeau baroque oboe with the first hole closed (B1 note). Simulation : blue. Measurement : orange. Played frequency : vertical line.

since only T-junctions are available at this day. Indeed, the third and fourth holes are made of two small holes for improving the altered notes intonation, while the ninth hole is composed of two opposite holes on the bell. Finally, the eighth and ninth holes are equipped with keys which is not accounted for in the current version of OpenWInD. For all these reasons, some discrepancies can be observed between measurement and simulation. Refined models and better geometric reconstruction should yield a better accordance.

Fig. 4 displays a sensitivity map of a Humeau baroque oboe (logarithm of the modulus of the gradient of the input impedance with respect to the hole position, in a frequency range corresponding to $\pm$ 10 cent around the played frequency). This map indicates how much a hole displacement will affect the different notes of the oboe. Other maps can be generated for other hole parameters as its length or its radius. They can prove useful in the development of new instruments in order to assess quantitatively which holes parameters are preponderant in the tuning of a given note, or conversely, which notes will be affected by the modification of one hole. This feature is based on the evaluation of the gradient in the framework of the Full Waveform Inversion (see [8]).

Sound computation can be done from an arbitrary shaped instrument, coupled with a valve (reed, see [6] on a french bassoon, or lips, see [11] on trumpets of the national collection Besson of Cité de la Musique - Philharmonie de Paris). The tuning of the valve parameters influences greatly the instrument sound, leading to various sounds ranging from “beginner” sound to “artificial mouth” sound, and musical sound. Even if it is not yet representative of what a musician would sound like on this instrument, this feature could prove useful for instrument makers by virtually assessing the influence of a geometric change on several targets as the ease of playing, the intonation, and even the relative tone quality.

4. PROSPECTS

One purpose of the OpenWInD project is to implement robust, accurate and efficient numerical methods to model wind musical instruments with state-of-the-art models. The public version of the software is available under GPLv3 licence [9] along with examples for using the different features. One other purpose is to provide instrument makers with tools to virtually assess some changes in the characteristics of the instruments under geometric alterations. The currently implemented models are making some important approximations which still prevent quantitative comparisons, but show very promising for qualitative assessment. Possible future improvements will include finer models for propagation, toneholes, radiation of toneholes with keys, or automatic embouchure control ; all these should bring numerical results closer to the fine degree of precision required in instrument making.

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